

5.0 WATER QUALITY CHARACTERIZATION

This section provides a summary of the available surface and groundwater quality information for the region surrounding the WPCF. The major topics discussed include the following:

- 5.1 Overview of Applicable Water Quality Objectives
- 5.2 Regional Surface Water Quality
- 5.3 Site-Specific Surface Water Quality
- 5.4 Regional Groundwater Quality
- 5.5 Site-Specific Groundwater Quality
- 5.6 Summary and Recommendations

The constituents of concern that are specifically addressed in this section are nitrate, EC, sodium, and chloride.

5.1 OVERVIEW OF APPLICABLE WATER QUALITY OBJECTIVES

As discussed in Section 1.2 the California anti-degradation policy requires that water quality in the state's waterways (both surface water and groundwater) be maintained such that constituent concentrations do not exceed the applicable water quality objectives. Therefore, a review of the applicable objectives for nitrate, EC, sodium, and chloride is warranted.

For surface water bodies, the applicable objectives are:

- California Toxics Rule Criteria (both for the protection of aquatic life and human health)
- EPA National Recommended Ambient Water Quality Criteria
- California and National Drinking Water Standards Maximum Contaminant Levels (MCLs)
- Agricultural water quality goals that are primarily outlined in the document *Water Quality for Agriculture, Food and Agriculture Organization of the United Nations—Irrigation and Drainage Paper No. 29, Rev. 1* (R.S. Ayers and D.W. Westcot, Rome, 1985)

For groundwater, only the MCLs and agricultural water quality goals are applicable.

The only applicable objective for nitrate-nitrogen is the 10-mg/L primary MCL.

There are several applicable water quality objectives from EC. The California drinking water recommended secondary MCL is 900 $\mu\text{mhos/cm}$, and the upper limit secondary MCL is 1,600 $\mu\text{mhos/cm}$. The agricultural water quality goal is 700 $\mu\text{mhos/cm}$. As outlined in Ayers and Westcot (1985), this goal is based on the potential for a reduction in crop yield for salt-sensitive crops such as beans, carrots, turnips, and strawberries. Note that although these crops are not typically grown in the region of the WPCF, the 700 $\mu\text{mhos/cm}$ goal would be applicable for the water bodies in the region (including groundwater).

The only applicable water quality objective for sodium is the agricultural water quality goal of 69-mg/L as a long-term average. As outlined in Ayers and Westcot (1985), this objective is intended to protect against adverse effects on sensitive crops when irrigated via sprinklers. This objective would be applicable for the water bodies in the region (including groundwater).

There are several applicable water quality objectives for chloride. The secondary MCL is 250 mg/L. The recommended agricultural water quality goal for chloride is 106-mg/L as a long-term average. As outlined in Ayers and Westcot (1985), this goal is intended to protect against adverse effects on salt sensitive crops when irrigated via sprinklers. Finally, the EPA National Recommended Ambient Water Quality Acute Criteria (1-hour maximum) is 860 mg/L and the EPA National Recommended Ambient Water Quality Chronic Criteria (4-day average) is 230 mg/L. The lowest criterion applicable for chloride is the agricultural goal of 106-mg/L, which would be applicable for the water bodies in the region (including groundwater).

A summary of the applicable water quality objectives for groundwater in the region of the WPCF is provided in Table 5-1.

Table 5-1. Water Quality Objectives for Groundwater in the Region of the Lodi WPCF

Constituent	Concentration	Applicable Objective
Nitrate	10 mg/L	Primary MCL
EC	700 $\mu\text{mhos/cm}$	Agricultural Goal
Sodium	69-mg/L	Agricultural Goal
Chloride	106-mg/L	Agricultural Goal

5.2 REGIONAL SURFACE WATER QUALITY

Surface water quality for San Joaquin County water sources can be categorized as either an eastside riverine source or a Sacramento-San Joaquin Delta source. As discussed in Section 3.3, the dominant riverine source in the region of the WPCF is the Lower Mokelumne River. A summary of the concentrations measured for select constituents of concern at monitoring stations in the Delta upstream of the WPCF and in the Lower Mokelumne River is provided in Table 5-2. A general discussion of the water quality of these two sources is presented below.

Table 5-2. Summary of Surface Water Quality

Constituent	Median Concentrations			
	Sacramento River at Hood ^(a)	San Joaquin River at Highway 4 ^(a)	Mokelumne at Woodbridge Dam	Delta at White Slough near WPCF ^(e)
Electrical Conductivity, μ mhos/cm	155	510	17 ^(b) /46 ^(c)	190
Total Dissolved Solids, mg/L	115	100	35 ^(b) /33 ^(c)	115
Hardness, mg/L	55	127	17 ^(b) /14 ^(d)	67
Chloride, mg/L	5	60	2 ^(b)	13
Sulfate, mg/L	7	65	3 ^(b)	9.5
Sodium, mg/L	10	56	2.5 ^(b)	NR ^(f)
Calcium and Magnesium, mg/L	18	41	6.0 ^(b) /4.7 ^(d)	NR ^(f)
NO ₃ -N, mg/L	0.5	6.1	0.06 ^(b)	0.6

(a) August 1998 – September 2001

(b) 1973 – 1974

(c) May – July 2006

(d) July 2006

(e) November 2001 – October 2002

(f) NR – Not reported

5.2.1 Sacramento-San Joaquin Delta

Generally, the Sacramento-San Joaquin Delta water quality is heavily influenced by flow from the Sacramento and San Joaquin Rivers, the intrusion of seawater from San Francisco Bay, operations of the Central Valley and State Water Projects, and agricultural and urban runoff. Delta water quality is also very dependant on the ability for higher quality Sacramento River water to dilute poorer quality San Joaquin water in the south and central Delta.

Appendix B contains additional details regarding Delta water quality data and selected figures and tables from the DWR publication *Municipal Water Quality Investigations (MWQI) Program Summary and Findings from Data Collected August 1998 through September 2001*. A summary of this data is provided in Table 5-2. As shown, Delta water quality near the WPCF is likely most influenced by the water quality of the Sacramento River and, to a lesser extent, the San Joaquin River. Water quality within the Sacramento River upstream of the WPCF is significantly better than the water quality within the San Joaquin River upstream of the WPCF.

5.2.2 Mokelumne River

Eastern San Joaquin County rivers and streams are sources of high water quality with generally low total dissolved solids loads. Typically, water quality is best during the winter and spring months and poorer through the irrigation season and early fall. The U.S. Geological Survey (USGS) has published water quality data collected between 1973 and 1994 for the Mokelumne River at the Woodbridge Dam. In addition, the City has collected some data in 2006 in the Mokelumne River. A summary of some of this data is provided in Table 5-2. As shown, the water quality in the Mokelumne River is significantly better than the water quality found in the Delta.

5.3 SITE-SPECIFIC SURFACE WATER QUALITY

As discussed in Section 3.3, the major water bodies located in the immediate vicinity of the WPCF property are the Delta and segments of the never-completed peripheral canal. A general discussion of the water quality of these two water bodies is presented below.

5.3.1 Delta Waterways Adjacent to WPCF

There is significantly variable spatial distribution of water quality within the Delta. In an effort to characterize the water quality of the Delta near the WPCF discharge, the City completed water quality monitoring monthly between November 2001 and October 2002 at a location in White Slough that was determined to lie outside the influence of the WPCF discharge. A summary of the major water quality parameters of concern with respect to groundwater quality that were monitored at this location was also provided in Table 5-2.

As shown in Table 5-2, water quality at the City's monitoring location in White Slough is better than the water quality observed in the San Joaquin River and more reflects the water quality observed in the Sacramento River. However, the water quality at this location is not as good as the water quality observed in the lower Mokelumne River. Therefore, water quality in the Delta near the WPCF discharge is likely more dominantly influenced by flows from the Sacramento River than the flows in the San Joaquin and Mokelumne Rivers.

Note that the highest concentrations of the parameters shown in Table 5-2 were observed during the winter months, with the maximum concentrations measured in February 2002. This pattern is consistent with the regional trend in salinity and nitrate loads that are presented in Appendix B.

The City has only completed minimal monitoring for nitrate in the small unnamed dead-end Delta channel located to the south of the main WPCF treatment facilities. Nitrate was not detected. EC data collected in Dredger Cut near the point of discharge since 2000 shows that the EC levels range from 200 to almost 900 micromhos per centimeter ($\mu\text{mhos/cm}$), with a median concentration of approximately 600 $\mu\text{mhos/cm}$. The water quality in the unnamed Delta channel on the City's property is expected to be similar. Water in this channel is also expected to interact with the shallow groundwater on the City's property and the water quality could also be influenced by this source.

5.3.2 Peripheral Canal

There are several open water bodies that are located adjacent to the WPCF property that are not connected directly to the Delta and instead are recharged by precipitation and interact with shallow groundwater. These bodies of water were borrow pits excavated along the alignment of the never-completed peripheral canal during construction of I-5. The City has only completed minimal monitoring for nitrate in these water bodies. This monitoring did not detect nitrate.

5.4 REGIONAL GROUNDWATER QUALITY

This section provides a summary of the available regional groundwater quality information with respect to the following parameters:

- EC
- General Chemistry
- Nitrate

The majority of information presented in this section was taken from the USGS publication entitled *Chemical Quality of Ground Water in San Joaquin and Parts of Contra Costa Counties, California* (Sorenson, 1981), which provides groundwater quality mapping for the WPCF and vicinity based on samples collected from supply wells prior to 1981. Additionally, the San Joaquin County Department of Environmental Health (SJCDEH) compiled nitrate results collected between 1996 and 2004 for land development projects and small system supply wells within a three mile radius of the WPCF. Tabulated results from this study are provided in Appendix C.

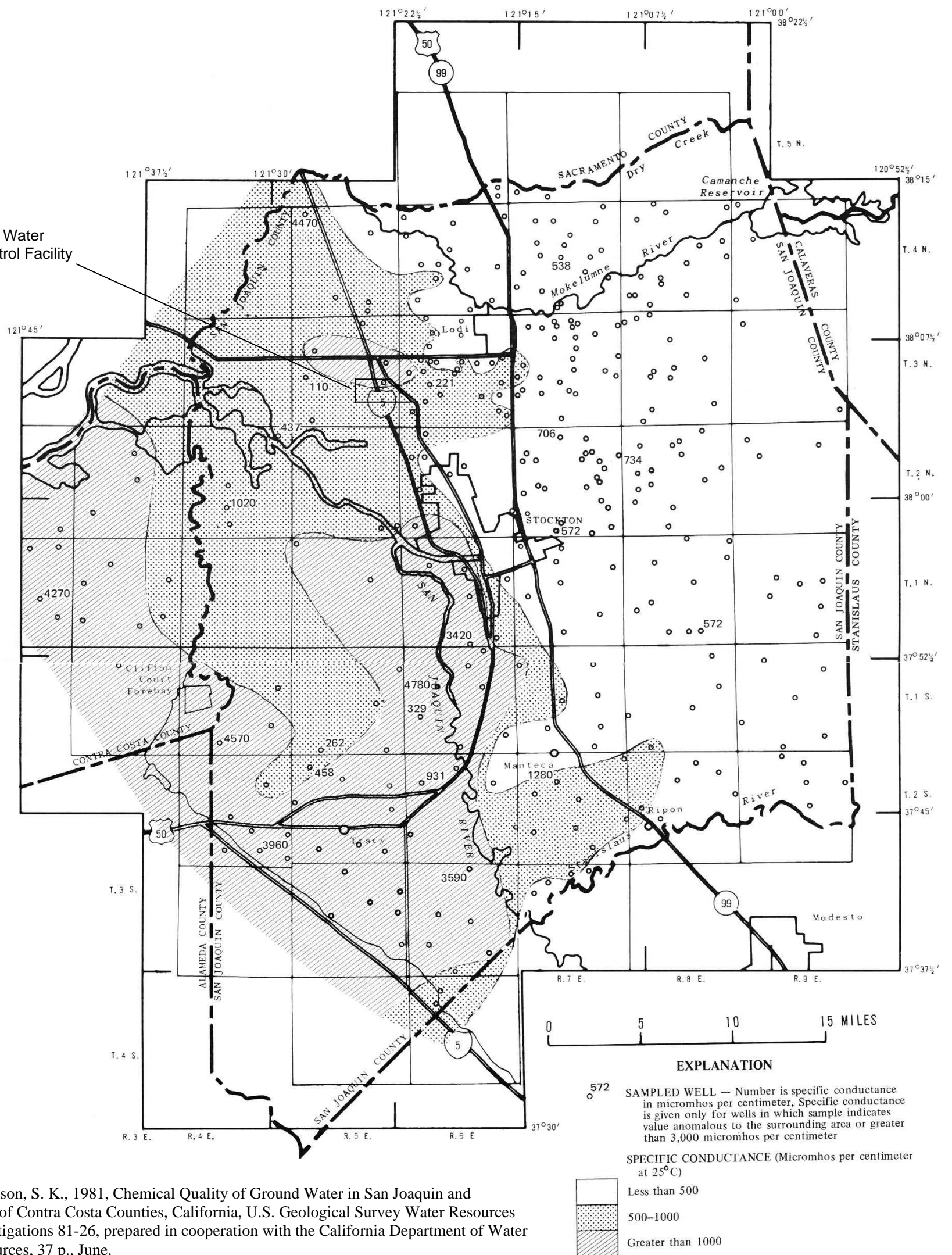
5.4.1 Electrical Conductivity

The regional distribution of EC in groundwater near the WPCF site is shown on Figure 5-1. As shown, the EC is elevated and exceeds 1,000 $\mu\text{mhos/cm}$ in a west-northwest to east-southeast trending zone encompassing the northern WPCF land application area and vicinity. This zone extends about five miles west-northwest and two miles east-northeast of the WPCF.

Figure 5-1 also shows that the EC ranges from 500 to 1,000 $\mu\text{mhos/cm}$ over a larger mapped area surrounding this zone of elevated EC. Therefore, all of the WPCF monitoring wells are within a region with EC levels greater than 500 $\mu\text{mhos/cm}$. The WPCF monitoring wells in the northern portion of the land application area are within a region with EC levels greater than 1,000 $\mu\text{mhos/cm}$ as mapped in the USGS report (Sorenson, 1981).

Figure 5-1 shows that EC levels exceed 1,000 $\mu\text{mhos/cm}$ primarily along the margins of the Delta. These elevated EC levels are thought to be the result of the brackish to saline surface waters that intruded into the Delta and San Joaquin River (as far south as Stockton) prior to the advent of water projects during the last century, especially the California State Water Project and the Federal Central Valley Project. This intrusion resulted in elevated EC in groundwater in and near the Delta.

White Slough Water
Pollution Control Facility



From: Sorenson, S. K., 1981, Chemical Quality of Ground Water in San Joaquin and Parts of Contra Costa Counties, California, U.S. Geological Survey Water Resources Investigations 81-26, prepared in cooperation with the California Department of Water Resources, 37 p., June.

Figure 5-1
City of Lodi White Slough WPCF
Groundwater Investigation
REGIONAL DISTRIBUTION SPECIFIC CONDUCTANCE
IN GROUNDWATER

After completion of the surface water storage and conveyance projects associated with the California State Water Project and the Federal Central Valley Project, releases of surface water from upstream reservoirs restricted the extent of saline surface water intrusion, especially during the irrigation season. Due to these releases of surface water, EC levels in shallow groundwater tend to be lower than during pre-development times in Delta lands that are irrigated with this project water. Therefore, the zone of elevated EC near the WPCF was probably once contiguous with a similar zone located to the south (Figure 5-1).

The USGS is currently engaged in a multiyear evaluation of groundwater in the eastern Delta region, including the vicinity of the WPCF. An initial phase of this study, which is scheduled to be completed in 2006, should provide additional information on the origin and distribution of chloride and EC in the vicinity of the WPCF.

5.4.2 General Chemistry

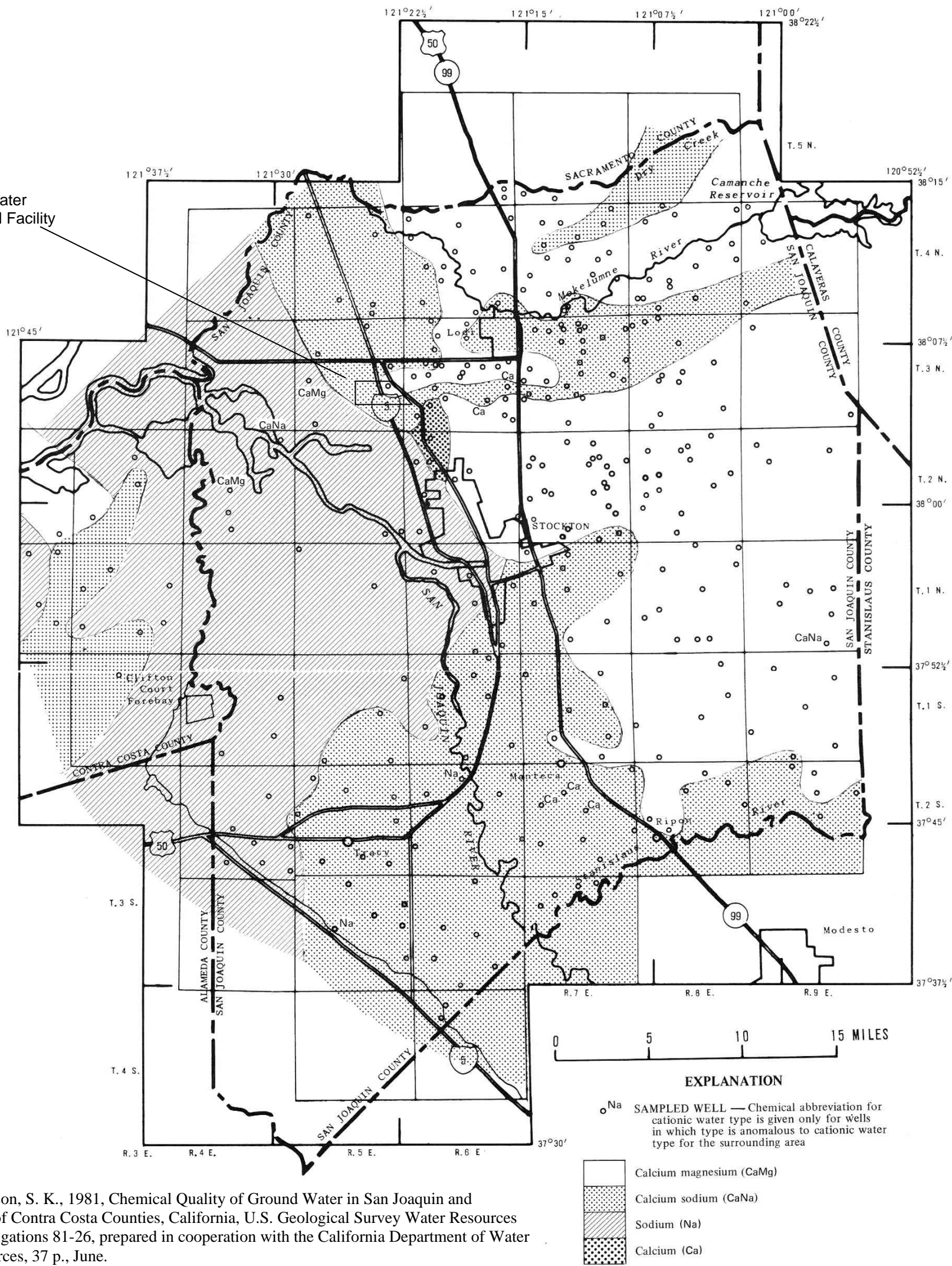
The regional distribution of the major cations in groundwater near the WPCF is shown on Figure 5-2. As shown, the primary cations contributing to EC are calcium and sodium followed by lower concentrations of magnesium (Sorenson, 1981). West of the WPCF, sodium is the dominant cation. Sodium is thought to be attributable to seawater intrusion in the Delta.

The regional distribution of the major anions in groundwater near the WPCF is shown on Figure 5-3. As shown, the WPCF overlies the boundary between two regional groundwater types as distinguished by the percentage of major anions. Chloride is the dominant anion on a percentage basis in the northwestern part of the agricultural reuse area and a large area to the west and northwest. The remainder of the WPCF area and the areas to the east and southwest are dominated by the bicarbonate anion on a percentage basis. Chloride is thought to be attributable to seawater intrusion in the Delta. Bicarbonate is a very common major anion in groundwater.

Figure 5-4 shows the regional chloride concentrations in groundwater. Chloride concentrations greater than 250 mg/L occur in a long, narrow zone extending south and east from the San Joaquin-Sacramento County line to the northern agricultural reuse area of the WPCF. The remainder of the WPCF area is outside of this zone in an area with chloride concentrations less than 100 mg/L, according to the USGS mapping (Sorenson, 1981).

The regional extent of the zone of elevated chloride concentrations over which the WPCF lies coincides approximately with the eastern boundary of the Delta (compare Figures 3-2 and 5-4). Because chloride is a conservative species (not appreciably sorbed on the aquifer matrix), it may have been partially flushed from groundwater under Delta lands irrigated with surface water after the implementation of irrigation projects during the last century. Near the eastern Delta margin, this flushing process appears to have been less complete, leading to the elevated concentrations observed near the WPCF (Figure 5-4). The in-progress USGS study may provide further information on the sources and extent of chloride in groundwater.

White Slough Water
Pollution Control Facility

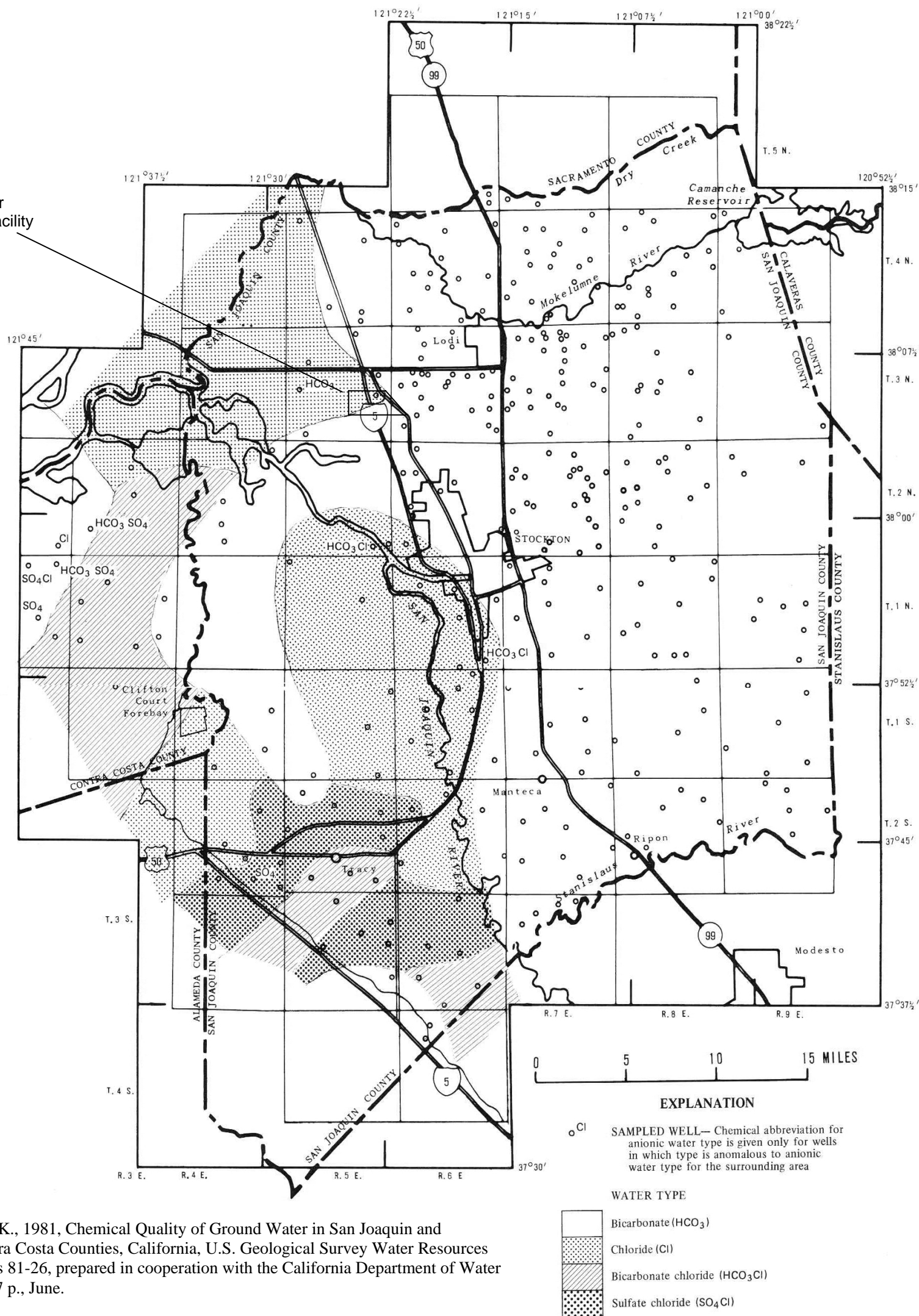


From: Sorenson, S. K., 1981, Chemical Quality of Ground Water in San Joaquin and Parts of Contra Costa Counties, California, U.S. Geological Survey Water Resources Investigations 81-26, prepared in cooperation with the California Department of Water Resources, 37 p., June.

Figure 5-2
City of Lodi White Slough WPCF
Groundwater Investigation

REGIONAL DISTRIBUTION OF MAJOR
CATIONS IN GROUNDWATER

White Slough Water
Pollution Control Facility

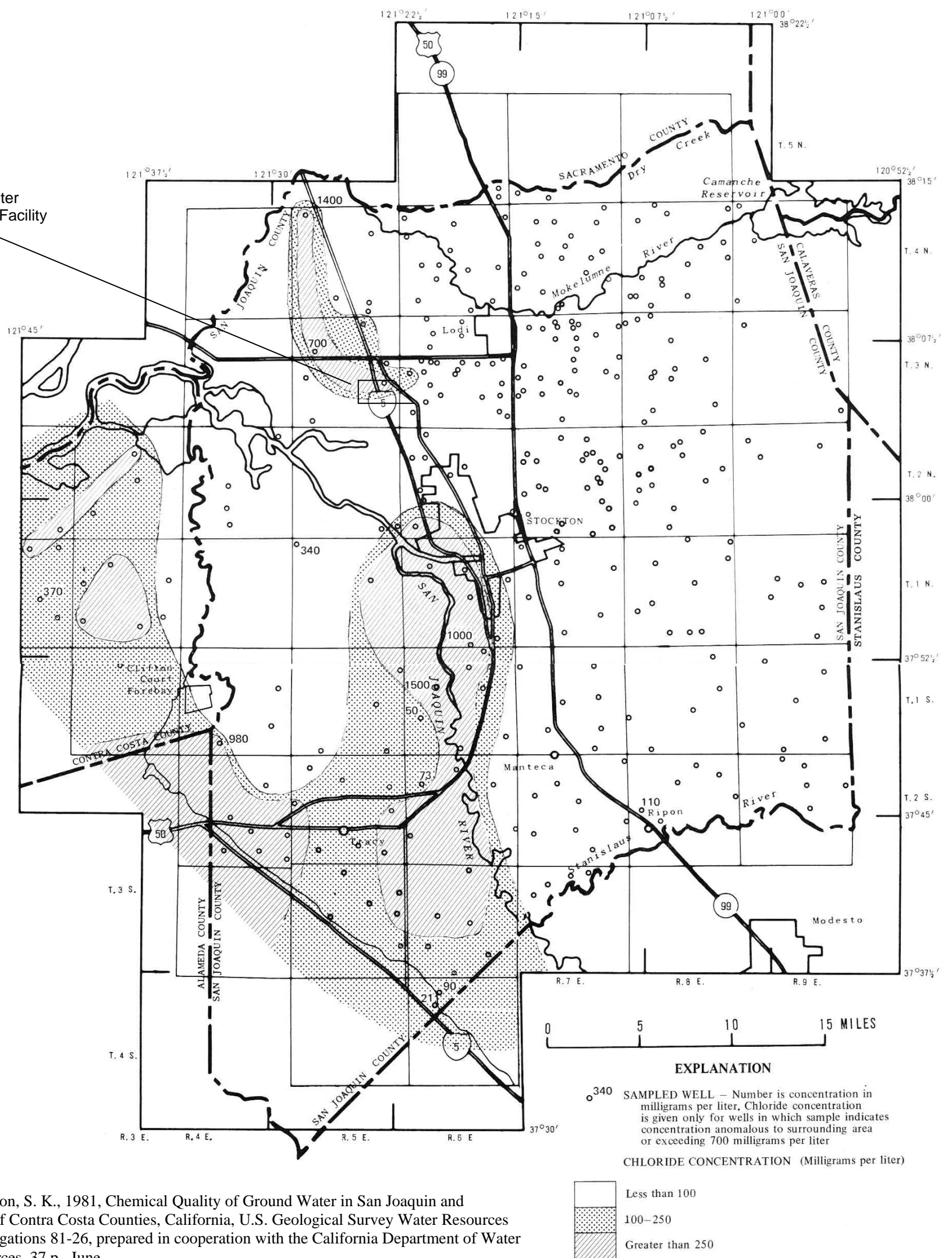


From: Sorenson, S. K., 1981, Chemical Quality of Ground Water in San Joaquin and Parts of Contra Costa Counties, California, U.S. Geological Survey Water Resources Investigations 81-26, prepared in cooperation with the California Department of Water Resources, 37 p., June.

Figure 5-3
City of Lodi White Slough WPCF
Groundwater Investigation

REGIONAL DISTRIBUTION OF MAJOR
ANIONS IN GROUNDWATER

White Slough Water
Pollution Control Facility



From: Sorenson, S. K., 1981, Chemical Quality of Ground Water in San Joaquin and Parts of Contra Costa Counties, California, U.S. Geological Survey Water Resources Investigations 81-26, prepared in cooperation with the California Department of Water Resources, 37 p., June.

Figure 5-4
City of Lodi White Slough WPCF
Groundwater Investigation
REGIONAL DISTRIBUTION OF CHLORIDE
CONCENTRATIONS IN GROUNDWATER

5.4.3 Nitrate

The regional distribution of $\text{NO}_3\text{-N}$ concentrations, as measured in supply wells in the vicinity of the WPCF prior to 1981 is shown in Figure 5-5. As shown, the $\text{NO}_3\text{-N}$ concentrations were generally less than 5 mg/L (Sorenson, 1981). The SJCDEH nitrate mapping, shown in Figure 5-6, indicates that nitrate ranged from below detection limit to 78.8 mg/L nitrate as nitrate ($\text{NO}_3\text{-NO}_3$) (equivalent to 17.5 mg/L $\text{NO}_3\text{-N}$) in water supply wells in the region during the 1996 to 2004 period. The median concentration was 25.7 mg/L $\text{NO}_3\text{-NO}_3$ (equivalent to 5.7 mg/L $\text{NO}_3\text{-N}$).

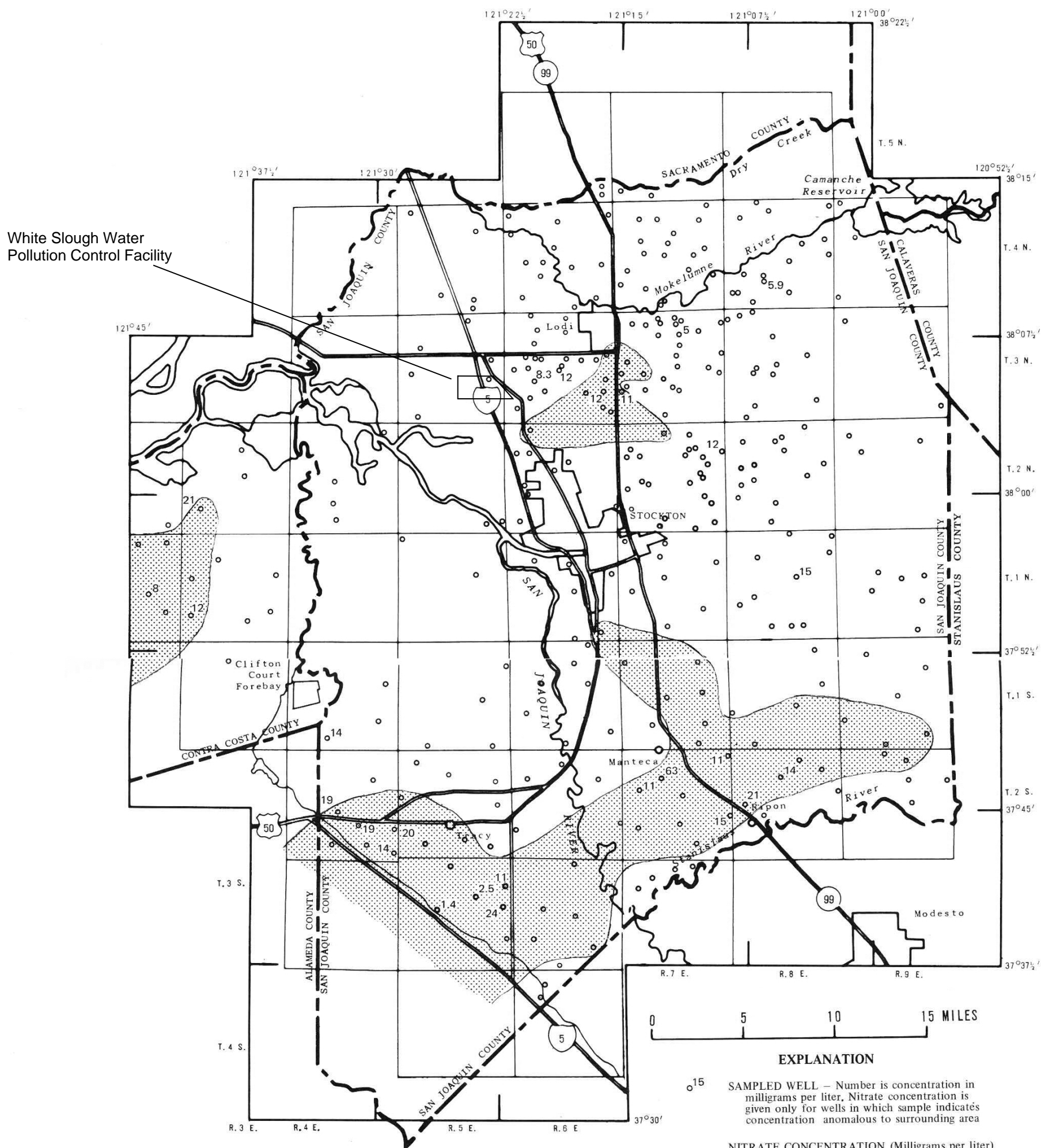
A comparison of the information presented in Figure 5-5 (Sorenson, 1981) to Figure 5-6 (SJCDEH) shows apparent increases in nitrate concentrations between samples collected in 1981 and earlier and those collected in the 1996 to 2004 timeframe. The apparent increases in nitrate concentrations are likely attributed to one or more of the following factors:

- Changes in land use
- Changes in groundwater gradient
- Sampling in the 1996-2004 timeframe of wells that were not sampled for the 1981 study, but had elevated groundwater nitrate concentrations prior to 1981

In the 1996 to 2004 sampling period, all of the highest nitrate concentrations were measured northeast of the WPCF. The known potential sources that could have contributed to the nitrate concentrations northeast of the WPCF are the WPCF itself, and the dairy operations to the north and east of the WPCF (Figure 4-2). The City has been land applying wastewater at the WPCF since the early 1950's, and the existing WPCF treatment facility has been in operation since 1966 (Section 2.1). As shown in Figure 4-2, the two major confined animal facilities associated with the Lima Ranch dairy northeast of the WPCF have been in operation since at least 1963 and 1975, respectively. Therefore, change in land use between the two sampling periods does not appear to be a significant factor contributing to the apparent change in nitrate concentrations.

For the WPCF to account for the nitrate increases in the area northeast of the WPCF, the overall groundwater gradient would need to be in this direction. As discussed in Section 3.6.1.1, regional groundwater flow is to the east-southeast from the WPCF, and it has been this way since at least the early 1970's. However, there does appear to be some groundwater deflection to the north-northeast of the WPCF property, probably due to groundwater pumping that is especially apparent northeast of monitoring well WSM-1 (Section 3.6.2.1.1).

As discussed in Section 3.6.2.1.1, additional monitoring wells are needed to help resolve local groundwater flow directions and help define the extent of drawdown caused by localized pumping in the area north and northeast of the WPCF property. These wells could also be used to differentiate potential sources of nitrate and nitrate concentrations in this area. One well should be located between the two confined animal facilities associated with the dairy located adjacent to the City's property to help resolve potential nitrate impacts associated with each dairy. A second well should be placed several thousand feet east (downgradient) of this dairy to help define the lateral extent of nitrate in this direction. A third deep monitoring well at WSM-1 would help in the assessment of potential vertical migration of nitrate due to the pumping to the northeast.



From: Sorenson, S. K., 1981, Chemical Quality of Ground Water in San Joaquin and Parts of Contra Costa Counties, California, U.S. Geological Survey Water Resources Investigations 81-26, prepared in cooperation with the California Department of Water Resources, 37 p., June.

Figure 5-5
City of Lodi White Slough WPCF
Groundwater Investigation
 REGIONAL DISTRIBUTION OF NITRATE
 CONCENTRATIONS IN GROUNDWATER

Note that the two wells sampled to the east-southeast of the WPCF in the 1996 to 2004 period had concentrations less than 5 mg/L NO₃-NO₃. Because the regional groundwater flow is predominately east-southeasterly from the WPCF (Section 3.6.1.1), the low concentrations detected are an indication that nitrate from the WPCF (and the local dairies) have not affected these wells.

Most of the sampled wells in the 1996 to 2004 period were located to the northeast of the WPCF, while in the 1981 sampling period only a few wells were tested in this area. Therefore, at least some difference between the USGS and San Joaquin County nitrate data are likely attributable to sampling of different wells during the two time periods. The WPCF and identified dairies have possibly led to increased nitrate concentrations in the area northeast of the WPCF, but such affects were not detected in the 1981 sampling event.

5.5 SITE-SPECIFIC GROUNDWATER QUALITY

This section provides a summary of the available site-specific groundwater quality information with respect to the following parameters:

- EC
- General Chemistry
- Nitrate

Most of the information presented in this section is based on the site-specific groundwater quality monitoring performed between 1989 and 2006 in shallow monitoring wells located on and near the WPCF and land application areas. These wells monitor groundwater at the water table. In contrast, the regional groundwater quality results discussed in the preceding section were collected from wells completed at significantly greater depths in the aquifer system. Note that the City has just begun the collection of general chemistry data. The analysis presented below for these constituents (major cations and anions) is based on a very limited data set and is considered preliminary.

5.5.1 Electrical Conductivity

The median EC measured in the WPCF monitoring wells between August 2001 and November 2005 is shown on Figure 5-7. The median EC ranged from 470 µmhos/cm in monitoring well RMW-3 to 1,750 µmhos/cm in WSM-2. The elevated levels of EC are not uniformly distributed beneath the WPCF land application areas as would be expected if the elevated EC was solely the result of WPCF land application practices.

All of monitoring wells east of the peripheral canal had median EC values greater than the 700 µmhos/cm agricultural water quality goal, and most exceed the recommended secondary MCL of 900 µmhos/cm. The highest levels were aligned along a northwest-southeast trending axis. Four of the highest median EC values were found in the wells closest to the east side of the peripheral canal but inside of the Delta boundary. Two of these wells, WSM-13 and WSM-16, are located outside of the agricultural reuse areas, indicating that regionally elevated EC influences the EC levels in these wells.

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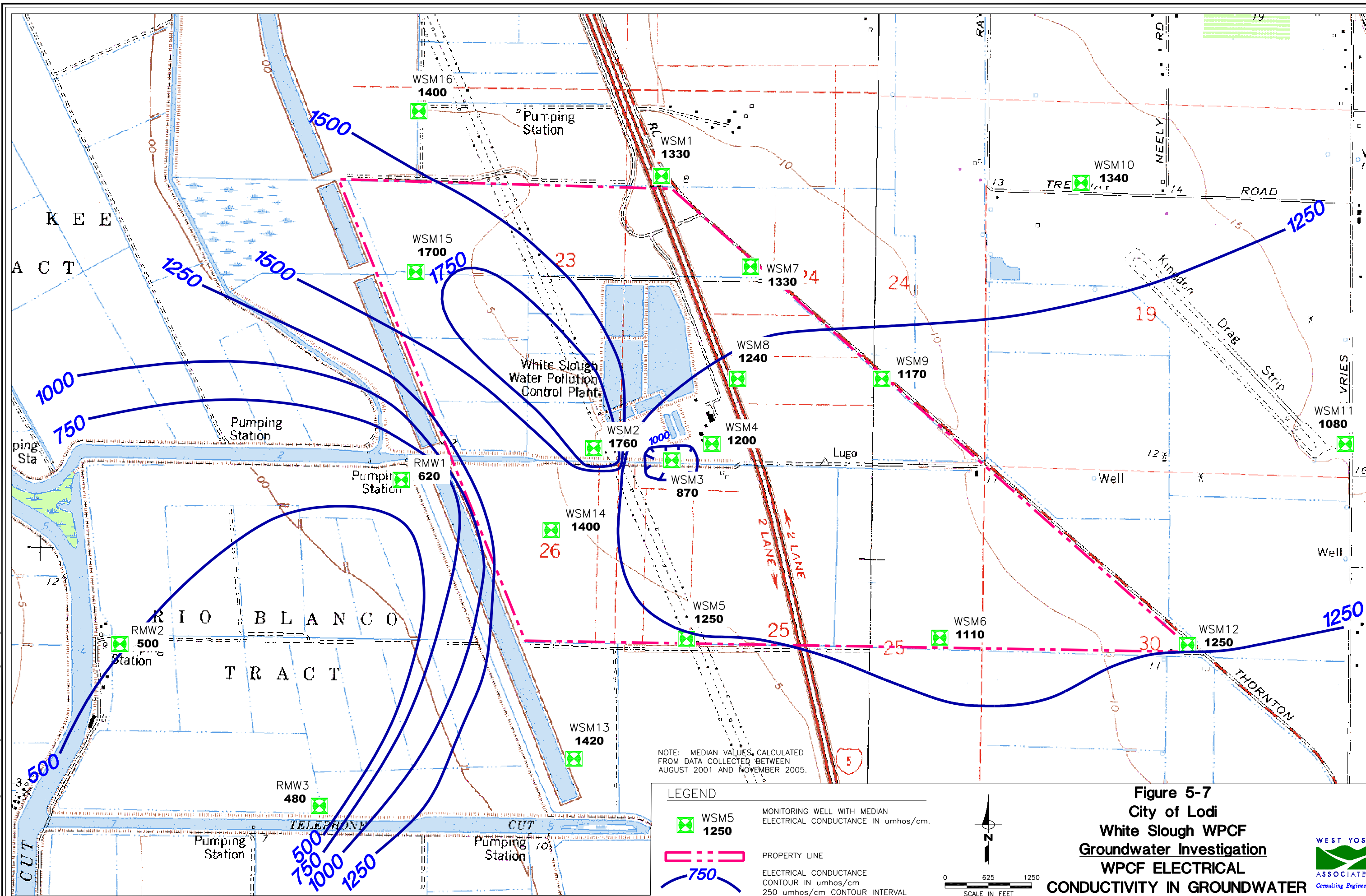


Figure 5-7
City of Lodi
White Slough WPCF
Groundwater Investigation
WPCF ELECTRICAL
CONDUCTIVITY IN GROUNDWATER

The highest median EC value was found in WSM-2, located near the WPCF infrastructure. Additional monitoring and evaluation of the water quality data from WSM-2 is needed to further assess whether the elevated EC level in WSM-2 can be attributed to regional conditions or not. Additional evaluation of whether the higher EC levels observed in this well are attributable to the WPCF is provided in Section 6.0 of this report.

The lowest median EC values were in wells RMW-1 through RMW-3. An important distinction regarding these wells is that lands in this area are irrigated with surface water, which as indicated in Table 5-2 has an average EC of approximately 190 $\mu\text{mhos/cm}$. Therefore, the shallow groundwater in this area would be expected to have a much lower EC than lands that remain affected by pre-development saltwater intrusion or that are irrigated with a groundwater source.

The EC levels in well WSM-3 were lower than anticipated based on comparison to the regional water quality data, and were the lowest of any of the wells except RMW-1 through RMW-3. The observed groundwater quality data for RMW-1 through RMW-3 is consistent with the use of surface water for irrigation in the Rio Blanco Tract. WSM-3 is adjacent to the unnamed Delta channel located on the City's property. The similarity of the EC data from WSM-3, and RMW-1 through RMW-3 implies a surface water influence at WSM-3. Further monitoring and evaluation of groundwater from WSM-3 should help determine whether these lower EC levels are significant to the groundwater compliance monitoring. Additional evaluation of whether the lower EC observed in WSM-3 are at least partially attributable to the WPCF is provided in Section 6.0 of this report.

The median EC contours were also shown in the cross-sectional view on Figures 3-6 through 3-11. Cross-section locations are shown on Figure 3-5. The cross-sections also show the general pattern of high EC along the east side of the peripheral canal and Delta boundary. They also show that a zone of relatively high EC extends eastward from well WSM-15 through wells WSM-1, WSM-2, WSM-7 and WSM-10.

Based on this available information, EC distribution patterns at the WPCF are consistent with the regional distribution of EC (compare Figures 5-1 and 5-7). This regional distribution of EC is probably attributable to the predevelopment intrusion of brackish to saline water in the Delta region.

Due to the apparent regional influence on groundwater EC, a monitoring well to the north-northwest of the WPCF land application area (outside of the influence of the WPCF but encompassed by the Delta water quality influence) would be an appropriate for defining the background EC in groundwater. Comparison of EC data from this background well will help in determining whether the WPCF and land application areas have contributed to increases in this parameter. As discussed in Section 3.6.2.1.2, a well in this location would also be helpful in defining groundwater flow directions to the north the of the WPCF property.

5.5.2 General Chemistry

Consideration of the dissolved cations and anions contributing to EC is needed to help resolve whether the levels of EC detected in the monitoring wells exceed the levels evident in the regional distribution. The City collected samples for general chemistry analysis during the fourth quarter 2005 and first quarter of 2006 groundwater sampling events. Stiff diagrams showing the major cations and anions for the individual wells are provided in Appendix D. Based on the limited temporal extent of this data set, the following discussion is considered preliminary and provisional. The City plans to collect additional general chemistry data, which will be used to validate and update the information presented here.

5.5.2.1 Cations

Based on this preliminary information, the primary cations contributing to EC beneath the City's property are calcium and sodium followed by lower concentrations of magnesium. This is consistent with the regional trends discussed in the preceding section and shown on Figure 5-2.

The spatial trends in the site-specific sodium concentrations are shown on Figure 5-8. Almost all of the wells on the City's property exhibited sodium concentrations that exceeded the 69-mg/L standard. These trends were similar to the trends in EC. The highest concentrations were detected in the northwestern quadrant of the agricultural reuse area, along the peripheral canal and Delta boundary, and in an eastward trending zone extending from well WSM-15 through wells WSM-2, WSM-1, WSM-7 and WSM-10.

Further monitoring and evaluation of the general water chemistry in wells WSM-15, WSM-2, WSM-1, WSM-7 and WSM-10 is needed to help resolve whether the sodium concentrations are consistent with the regional trends. Additional evaluation of whether the elevated concentrations of sodium in these wells are attributable to the WPCF and/or the land application area is provided in Section 6.0 of this report.

As with EC, the sodium concentrations in WSM-3 were lower than any of the wells except RMW-1 through RMW-3, and were less than the 69-mg/L standard. This data further implies that the observed groundwater quality in WSM-3 has a surface water influence (particularly due to this wells proximity to the unnamed Delta channel located on the City's property). Further monitoring and evaluation of groundwater quality in this well is needed to assess the importance of this influence. Additional evaluation of whether the lower concentrations of sodium observed in this well are at least partially attributable to the WPCF is provided in Section 6.0 of this report.

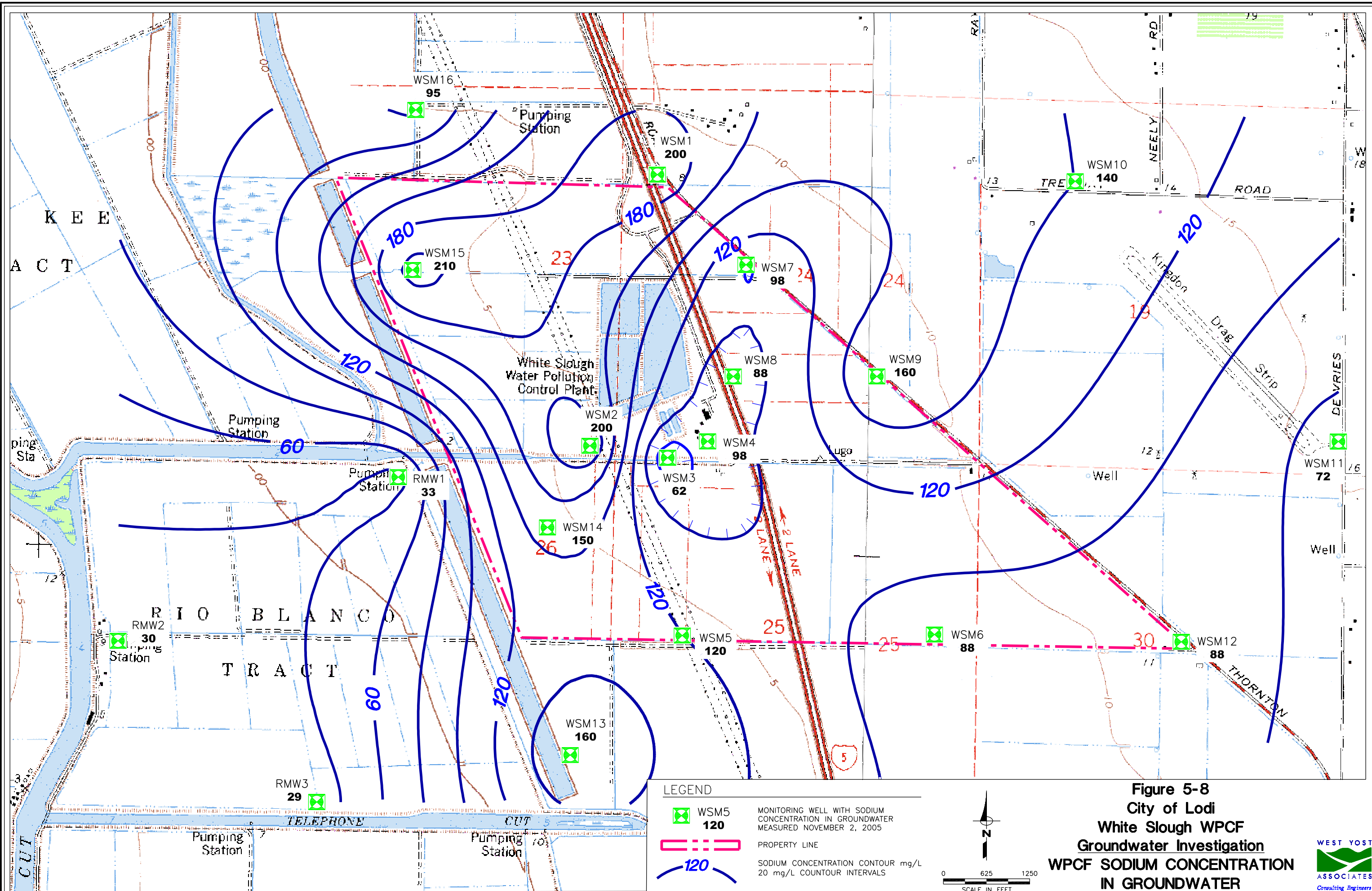
The consistency between distribution trends for EC and chloride further substantiates the conclusion that a monitoring well to the north-northwest of the WPCF land application area would be appropriate for defining the background salinity in local groundwater.

5.5.2.2 Anions

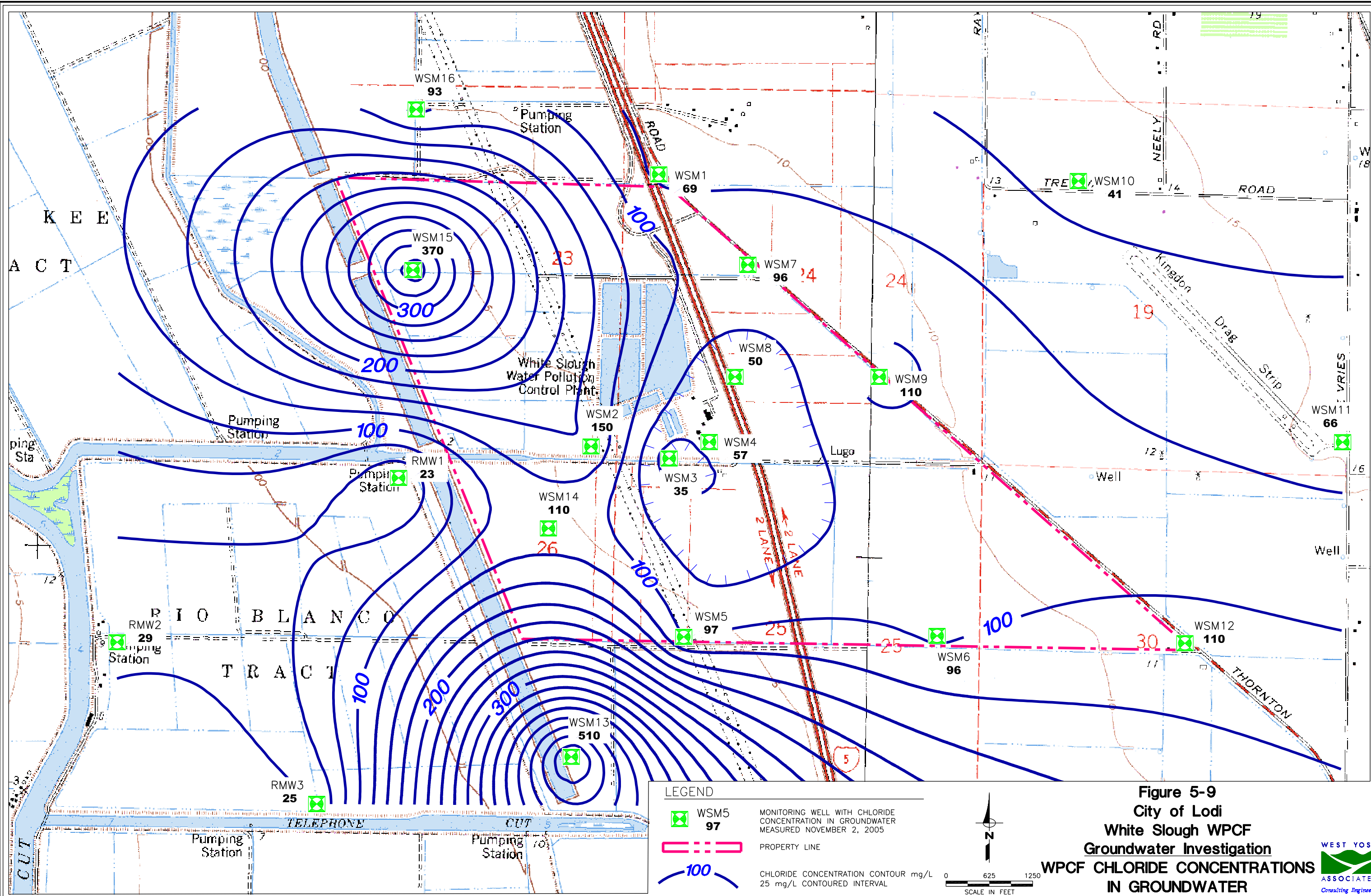
In general, the spatial trends in anion concentrations are consistent with regional trends shown on Figure 5-3. Bicarbonate was the dominant anion in all of the wells. However, elevated concentrations of chloride were detected in several wells.

The spatial trends in the site-specific chloride concentrations are shown on Figure 5-9. Several wells demonstrated chloride concentrations that exceeded the 106-mg/L standard. The highest concentrations were more restricted to the area near the east edge of the peripheral canal and Delta boundary. WSM-13 and WSM-15 were the only wells in which the chloride concentrations exceeded the 250-mg/L MCL. However, WSM-2 also had somewhat elevated concentrations. Note that the maximum chloride concentration shown in Figure 5-9 (510 mg/L in WSM-13) was detected outside of the WPCF land application area. In other WPCF areas, there were no apparent trends in the chloride concentrations.

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Comparison of Figures 5-4 and 5-9 shows that the regional distribution of chloride in groundwater is reflected in the site-specific results. On a regional basis, chloride concentrations are elevated along the eastern margin of the Delta, and this seems to explain the high concentrations of chloride observed in the wells near the Delta boundary. As described in more detail in Section 6.0, chloride is not a major constituent in waste streams entering the WPCF, and it appears unlikely that the chloride concentrations detected in the WPCF monitoring wells exceed the range of chloride concentrations observed regionally. Therefore, the regional groundwater conditions are most likely affecting the WPCF monitoring wells more than impacts from the WPCF infrastructure or land application areas.

Well WSM-3 also had the lowest chloride concentrations of any of the wells except RMW-1 through RMW-3, further substantiating implication of a surface water influence at WSM-3. Further monitoring and evaluation of groundwater from WSM-3 should help determine whether these lower concentrations are significant to the groundwater compliance monitoring. Additional evaluation of potential WPCF influence is provided in Section 6.0 of this report.

The consistency between distribution trends for EC, chloride, and sodium confirm that a monitoring well to the north-northwest of the WPCF land application area would be appropriate for defining the background salinity in local groundwater.

5.5.3 Nitrate

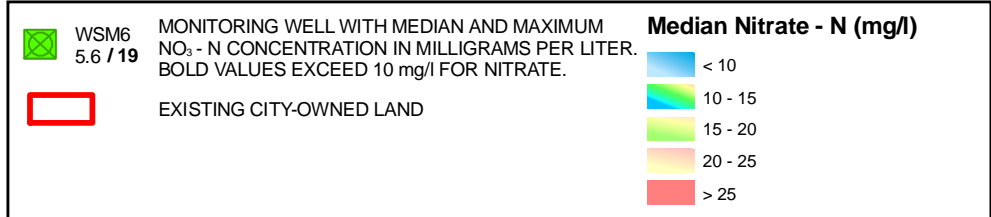
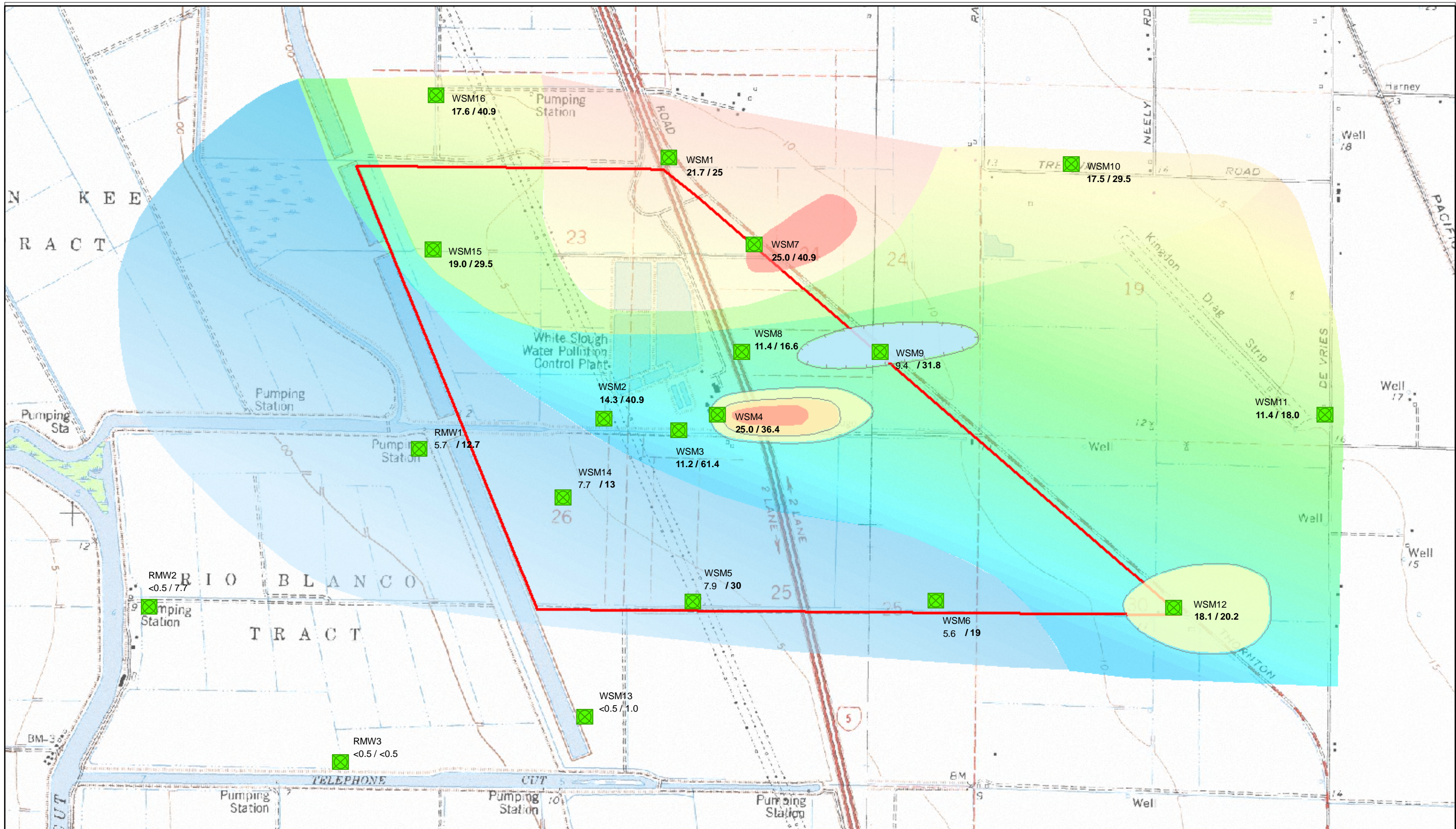
A discussion of the spatial and temporal trends in nitrate groundwater concentrations is provided below.

5.5.3.1 Spatial Nitrate Trends

Contours of the median nitrate concentrations measured in the WPCF monitoring wells between August 2001 and November 2005 are shown on Figure 5-10. Maximum nitrate concentrations over the same period are also posted on Figure 5-10.

The median concentrations ranged from below the detection limit in wells RMW-2 and RMW-3 to 26.2 mg/L NO₃-N in well WSM-7. Median concentrations exceeded the 10-mg/L primary MCL in all of the wells except those located in the Rio Blanco Tract and the southwestern quadrant of the agricultural reuse area. Maximum concentrations ranged from below detection limits in well RMW-3 to 61.4 mg/L in WSM-3. Maximum concentrations exceeded the MCL in all of the wells except those located in the Rio Blanco Tract and WSM-13, located south of the City's agricultural reuse area.

The lowest nitrate concentrations were detected to the southwest of the WPCF. Based on groundwater flow directions and velocities (Section 3.0), there is limited potential for significant southwesterly groundwater transport of nitrates from the WPCF. Another factor influencing the nitrate concentrations in this area may be the presence of hydric soils in the Delta area. Hydric soils are soils sufficiently wet to develop anaerobic conditions during the growing season (USDA NRCS, 2006). These anaerobic conditions could lead to denitrification beneath Delta lands, including the Rio Blanco Tract (Figure 5-10). Nitrates are almost never detected in Rio Blanco Tract wells RMW-2 and RMW-3.



NOTE:
MEDIAN AND MAXIMUM VALUES CALCULATED FROM DATA
COLLECTED BETWEEN AUGUST 2001 AND NOVEMBER 2005.

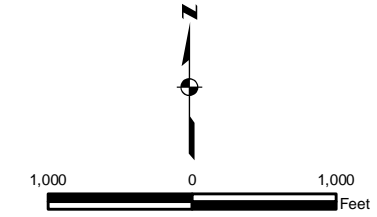


Figure 5-10
City of Lodi
White Slough WPCF
Groundwater Investigation
WPCF MEDIAN AND MAXIMUM NITRATE
CONCENTRATIONS IN GROUNDWATER

In areas where groundwater median NO₃-N concentrations were greater than the 10-mg/L MCL, the spatial variations in nitrate concentrations were correlated with apparent nitrate sources and the variation in saturated sand thickness (compare Figure 4-11 and Figure 5-10). The lowest concentrations tended to be detected where the saturated sands were thinnest or nonexistent (e.g., wells WSM-8 and WSM-9). The higher concentrations were associated with thicker sands or, presumably, were near nitrate sources. As discussed in Sections 3.5.2 and 3.6.2, the extent of the sands affects the local groundwater flow rates and transport of relatively mobile constituents, such as nitrate.

With the exception of WSM-4, the highest median concentrations were found north and northeast of the effluent storage ponds (WSM-1 and WSM-7). As described in Section 3.6.1.1, the groundwater flow direction from most areas of the WPCF site is to the east-southeast. Beneath the northeastern portion of the property, however, groundwater flow appears to be northeasterly in the fall, suggesting that groundwater pumping to the northeast influences the gradient (Figure 3-13). As discussed in Section 5.4.3, several additional wells are recommended in this area to help differentiate potential sources of nitrate and define the lateral and vertical extent of nitrate migration in the groundwater.

The relationship between potential sources and nitrate concentrations is most apparent in the maximum nitrate concentration results on Figure 5-10. The wells with the highest maximum nitrate concentrations are located near potential sources. These wells include:

- WSM-2 located southwest of the WPCF
- WSM-3 and WSM-4, located near WPCF influent pipelines
- WSM-7 located northeast of the effluent storage ponds
- WSM-9 located east of the effluent storage ponds and the WPCF

Note that several of these wells also penetrate significant thicknesses of saturated sand (Figure 4-11).

The lateral extent of the nitrate observed in these wells is not well defined along the eastern side of City's monitoring well network. One new well located on Thornton Road due east of WSM-4 will help to assess the lateral extent of elevated nitrate detected in the vicinity of WSM-2, WSM-3 and WSM-4 and will provide more complete monitoring of the land application area.

In addition to these new wells, cone penetrometer testing (CPT) in conjunction with Hydropunch sampling should be used to assess stratigraphy and aquifer permeability, and extract groundwater samples for analyses of nitrate concentrations as a function of depth along the following three transects:

- From WSM-1 to WSM-10.
- From a new well located between the two confined animal facilities associated with the dairy that is adjacent to the City's property to a new well several thousand feet east (downgradient) of this dairy.
- From WSM-4 to a new well located on Thornton Road due east of WSM-4.

The CPT/Hydropunch transects should be performed and evaluated prior to construction of the monitoring wells. Each CPT/Hydropunch location will provide information on the stratigraphy, aquifer permeability and nitrate concentrations as a function of depth. The geotechnical and nitrate concentration data should then be used to estimate the target depths of the monitoring wells on either end of the transects. This will ensure that vertical transport of nitrate along groundwater flow paths is addressed. Analyses of nitrogen and oxygen isotopes along these transects may help differentiate sources and assess the extent of nitrate transport from the sources. Nitrogen isotope data have been used to statistically differentiate sources of nitrate, including fertilizer, animal and sewage sources (Fogg, et. al., 1998). The relative proportions of oxygen and nitrogen isotopes in nitrates have been used to differentiate nitrate sources and identify denitrification beneath dairy lagoons and in areas with hydric soils (Kendall and McDonnell, 1998; Showers, et. al., 2006).

WSM-16, located north of the WPCF land application area has also demonstrated elevated nitrate concentrations. As discussed in Section 3.6.2.1.2, the hydraulic gradient between WSM-16 and the WPCF land application area is very low and is frequently southerly, limiting the potential for northward transport from the land application area (and increasing the potential for an offsite source to be affecting groundwater quality in the vicinity of WSM-16). Therefore, the major dairy operation located northeast of the WPCF (or a yet unidentified sources to the north) could be affecting the water quality measured in WSM-16. Historically, the elevated nitrate concentration and groundwater flow gradients have been southerly from WSM-16 to WSM-2, indicating southerly transport of nitrate in groundwater. Therefore, the relatively high nitrate concentrations detected in WSM-2 could also be attributable to a source or sources in the area north of the WPCF site. The recommended additional monitoring wells to the north and northeast of the WPCF discussed previously will help to define the nitrate contributions to these monitoring wells from the potential sources further to the north and northeast.

A source at the WPCF could also potentially be affecting nitrate concentrations in the vicinity of WSM-2. Specifically, migration of a plume originating in the vicinity of WSM-3 and WSM-4 could explain the elevated maximum concentrations observed in WSM-2. As discussed in Section 3.6.2.1.2, the groundwater elevation in WSM-2 is sometimes less than the groundwater elevation in WSM-3 and WSM-4, providing evidence for flow from WSM-3 towards WSM-2 under some conditions. If the lateral extent of a nitrate plume in the vicinity of WSM-3 and WSM-4 extends further west from WSM-3 than is presently known, there is potential for this plume to move towards WSM-2 and, eventually, WSM-14. The new well at the WPCF discussed in Section 3.6.2.1.2 will provide more accurate and detailed information on the groundwater elevations and flow directions beneath the main WPCF facility and help to identify WPCF sources that could be affecting WSM-3 and WSM-4. This well would also help differentiate on-site and off-site sources that may be affecting WSM-2. This well could be located southwest of the sludge lagoon to enable a more accurate measurement of the depth to groundwater beneath the facility, and verify that releases from the sludge lagoon are not occurring.

Finally, two new wells are recommended further to the north and east of the dairy operation that is adjacent to the City's property to assess background concentrations of nitrate in groundwater. These wells should be sited in land use areas that are similar to the land use in the vicinity of the WPCF, (i.e., in irrigated agriculture areas). Additionally, these wells are expected to be located upgradient of the WPCF and this dairy based on the regional groundwater flow information shown in Appendix A.

Note that a well in the area to the west would not be appropriate for defining the background conditions because of the different land and water use and soils of this region.

5.5.3.2 Temporal Nitrate Trends

Temporal trends in nitrate concentrations were evaluated to assess whether nitrate concentrations in groundwater were correlated with groundwater elevations. Graphs of the nitrate concentrations and groundwater elevations over time in each of the WPCF monitoring wells are provided in Appendix E. Well locations are shown on Figure 5-10. As can be seen in the graphs, there is no consistent, predictable relationship between nitrate concentrations and groundwater elevations in most of the wells. The graphs do show that nitrate concentrations vary significantly with time in some of the wells, as is expected based on the relative mobility of nitrate in groundwater and the seasonality of some nitrate sources.

Four patterns of nitrate variation were noted on the graphs shown in Appendix E:

- Wells with seasonal variability
- Wells with sporadic variability
- Wells with uniformly increasing or decreasing trends
- Wells with limited variability

These patterns are discussed below.

5.5.3.2.1 Wells with Seasonal Nitrate Variability

Some of the wells exhibit seasonal variability in nitrate concentrations. As discussed in Section 3.6.2.2, groundwater levels near the WPCF also vary seasonally (under the influence of precipitation between roughly October and March, and groundwater pumping between roughly April and September of each year), suggesting a possible correlation with nitrate concentrations. However, the lack of correlation of nitrate concentrations with groundwater elevations on either shorter (months) or longer (years) term scales in these same wells is an indication that the seasonal variations in nitrate concentrations and groundwater elevations are due to independent causes.

The wells that exhibit apparent seasonal variation include the following (Appendix E and Figure 5-10):

- WSM-03 and WSM-04 near the WPCF influent pipelines.
- WSM-7, northeast and downgradient of the effluent storage ponds on the border of the land application area and adjacent to an unlined irrigation conveyance ditch.

The depth to water in these wells is not drastically different from other wells that do not show the same degree of seasonal variability (compare WSM-2 and WSM-3, or WSM-7 and WSM-9 in Appendix E). This is an indication that depth to groundwater is not the primary control on the variation. Instead, proximity to potential sources and soil properties affecting nitrate fate and transport in the unsaturated zone are likely the dominant controlling factors on whether seasonal fluctuations are observed in the wells.

5.5.3.2.2 Wells with Sporadic Nitrate Variability

Other wells show significant historical variation in nitrate concentrations characterized by sporadic rapid increases and decreases. Examples of wells in this category include the following (Appendix E and Figure 5-10):

- WSM-5 and WSM-6, near the southern border of the land application area.
- WSM-15 and WSM-16, located north of the WPCF land application area.

The trends observed in WSM-5 and WSM-6 may be explained by over-application of nitrogen in the early to mid-1990's timeframe near WSM-5. Reduction in land application rates in this area may explain the declining concentrations thereafter. Subsequent easterly transport of the nitrate in groundwater could explain the peak in concentrations that occurred in WSM-6 in the 1998-2000 timeframe. Alternatively, the 1998-2000 peak in nitrate concentrations could be the result of a separate over-application event near WSM-6. The City was not monitoring field nitrogen application rates during these periods, so there is currently no way to verify these explanations of the historical trends in WSM-5 and WSM-6.

The variation in nitrate concentrations in WSM-16 is difficult to associate with a WPCF source. The well is located outside of the northern boundary of the WPCF land application area. The peak concentration of 40.9 mg/L in WSM-16 occurred during a timeframe when groundwater elevations in WSM-15, a well located within the WPCF land application area, were very similar to WSM-16. In fact, comparison of the groundwater elevation trends in the two wells shows that there is rarely, if ever, an appreciable gradient that could drive groundwater flow from the WPCF northward toward WSM-16.

At times, the gradient is southerly from WSM-16 toward the WPCF land application area. Southerly flow from an as-yet unidentified source towards the WPCF and associated transport of nitrate could explain why the nitrate concentration in WSM-16 peaked in September 2003, then declined, and the concentrations in WSM-15 began to rise thereafter and reached a peak in August 2004. The recommended monitoring wells further to the north and northeast of the WPCF will help to resolve flow directions and the source of nitrate concentrations in WSM-16.

5.5.3.2.3 Wells with Uniform Nitrate Variability

A few wells show variations in nitrate concentrations that are increasing or decreasing uniformly. These include the following (Appendix E and Figure 5-10):

- WSM-2, near the southwest corner of the WPCF.
- WSM-9, on the eastern boundary of the WPCF land application area.
- WSM-10, located several thousand feet east of the northern boundary of the WPCF.

The nitrate concentrations in WSM-2 and WSM-9 have been increasing uniformly, while the concentration in WSM-10 has been decreasing uniformly during the last several years. The relatively uniform rates of increase or decrease observed in these wells may indicate that the wells are relatively isolated from nitrate sources, either by distance (WSM-10), the presence of low permeability aquifer materials (WSM-9) or low groundwater gradients (WSM-2). This

isolation and nitrate fate and transport processes in groundwater may dampen shorter term fluctuations resulting in more uniform trends in nitrate concentration.

Comparison of the recent nitrate concentration trends in WSM-2 and WSM-9 shows that the two wells are exhibiting similar increasing trends (Appendix E). As discussed in Section 5.5.3.1, the concentrations observed in WSM-2 could be due to a nitrate source to the north of WSM-16. Alternatively, migration of a plume originating in the vicinity of WSM-3 and WSM-4 could explain the concentration trends observed in WSM-2 and WSM-9. There is evidence that groundwater could flow from WSM-3 towards WSM-2 under some conditions. Furthermore, WSM-9 is always down gradient of WSM-3 and WSM-4, indicating that nitrate could be transported from the WSM-3/WSM-4 area towards WSM-9. Further monitoring of these wells will help to clarify the significance of the observed nitrate trends. The recommended well at the WPCF site will help resolve groundwater flow directions in this area.

5.5.3.2.4 Wells with Limited Nitrate Variability

Other wells have exhibited stable nitrate concentrations. Wells with relatively stable nitrate concentrations in excess of the 10-mg/L MCL include the following (Appendix E and Figure 5-10):

- WSM-1, near the northeast corner of the WPCF.
- WSM-8, near the land application area boundary east of the effluent storage ponds.
- WSM-11, located several thousand feet east of the eastern boundary of the WPCF land application area.
- WSM-12, located at the southeastern corner of the WPCF land application area.
- WSM-14, approximately 1,000 feet southwest of the WPCF.

The stability of the nitrate concentration trends in these wells may have two different explanations.

The nitrate concentrations in WSM-1 and WSM-8 may be attributable to relatively uniform source contributions. These wells are relatively close to the WPCF and the City's storage ponds. The proximity of the wells to these facilities could mean that the wells are influenced more by a sources associated with them than by the land application area. Additional discussion of these potential source contributions is provided in Section 6.

The situation is less clear at WSM-14. The well is located further from the WPCF in the land application area (Figure 5-10). Based on a somewhat limited monitoring history, WSM-14 has not exhibited either seasonal or sporadic fluctuations in nitrate concentrations. Although relatively stable, the concentrations have increased slightly to exceed the 10-mg/L MCL for nitrate. The increasing concentration trend observed in WSM-2 is also possibly reflected, but to a lesser extent, in WSM-14. Possible explanations are that nitrate is transported to these wells from the north, from the vicinity of WSM-16, or that nitrate released near WMS-3 and WSM-4 has been transported in groundwater towards WSM-2 and WSM-14. Future monitoring results from WSM-16, WSM-2, WSM-3, WSM-4, WSM-14, and the new well recommended at the WPCF site will help resolve groundwater flow directions and should provide evidence regarding the potential for nitrate plume migration in the vicinity of these wells.

The uniform nitrate concentrations observed in WSM-11 and WSM-12 are probably the result of the wells' relatively great distance from potential sources. Groundwater transport processes between source areas and the wells may have smoothed sporadic and seasonal fluctuations observed in other wells closer to sources.

5.6 SUMMARY AND RECOMMENDATIONS

Comparison of available surface water and regional and site-specific groundwater quality data indicates that groundwater quality at the WPCF and associated land application areas is highly variable and significantly affected by regional-scale trends. These trends are largely influenced by current and historic land and water use variability in the region surrounding the property. Water quality parameters of particular concern are EC, sodium, chloride, and nitrate.

5.6.1 Electrical Conductivity, Sodium and Chloride

Groundwater EC is elevated regionally. Based on the regional groundwater quality information, the major constituents contributing to EC lead to classification of the groundwater as either a calcium-sodium-chloride type or a calcium-sodium-bicarbonate type.

Relatively high concentrations of chloride and sodium in some WPCF wells located closest to the Delta suggest that the EC levels in these wells may be the result of processes controlling regional groundwater quality. Specifically, intrusion of brackish to saline water into the Delta prior to the advent of Delta water projects during the last century has led to elevated groundwater salinity in this region.

Currently, as a result of these Delta water projects, surface waters from upstream reservoirs restricts the extent of saline surface water intrusion, especially during the irrigation season. Therefore, salinity levels in shallow groundwater in areas west of the City's property that are irrigated with this released water are more similar to surface water quality than to the regional conditions.

The USGS is currently engaged in a multiyear evaluation of groundwater in the eastern Delta region, including the vicinity of the WPCF. An initial phase of this study, which should be completed in 2006, should provide additional information on the origin and distribution of chloride and EC in the vicinity of the WPCF.

Due to the regional influences on groundwater salinity levels, an additional well to the north of the WPCF land application area would be appropriate for monitoring background EC and general chemistry in groundwater. This well would need to be located outside of the influence of the WPCF land application area but within the region in which groundwater EC and general chemistry is influenced by the Delta. This well could also be used to help define the groundwater flow directions to the north of the WPCF. Comparison of EC and general chemistry data from this background well will help in determining whether the WPCF and land application areas have contributed to increases in these parameters.

5.6.2 Nitrate

Nitrate concentrations in groundwater exceed the 10-mg/L MCL in the immediate vicinity of the WPCF and in all WPCF monitoring wells to the north and east of the WPCF. The regional nitrate data shows that nitrate concentrations in supply wells frequently exceed the MCL to the northeast of the WPCF, but are generally less than 5 mg/L to the east.

Differentiating between the regional and potential WPCF source contributions to the nitrate groundwater concentration observed on and around the WPCF site is much more difficult than for salinity because the lateral and vertical extent of nitrate has not been clearly defined. Therefore several additional monitoring wells are recommended as shown in Figure 5-11.

These additional monitoring wells can be described as follows:

- Two monitoring well located northeast of the WPCF to establish the extent of the northeasterly flow, assess the extent of nitrate transport from the WPCF, and evaluate the nitrate impacts of the dairy located to the northeast of the WPCF. One well should be located between the two confined animal facilities associated with the dairy located adjacent to the City's property, and one well should be placed several thousand feet east (downgradient) of the dairy to help define the lateral extent of nitrate.
- Two new wells further to the north and east of the dairy located adjacent to the WPCF to assess background concentrations of nitrate in groundwater. These wells should be sited in land use areas that are similar to the land use in the vicinity of the WPCF. Based on the regional groundwater flow information, wells located in this area will be upgradient of the WPCF and the dairy. Comparison of nitrate data from these background wells will help in determining whether the WPCF and land application areas have contributed to increases in this parameter.
- One deeper well at the site of WSM-1 to assess the vertical extent of nitrate northeast of the WPCF site.
- One new well located to the north of WSM-16 to assess the potential for transport from this area to WSM-16 and southerly to the City's property (note that this well would also serve as the background monitoring well for EC).
- One new well located on Thornton Road, due east of WSM-4 to assess the extent of elevated nitrate detected in the vicinity of WSM-4 and to provide more complete monitoring of the land application area.
- One new well located southwest of the sludge lagoon will help the resolve the sources of nitrate affecting WSM-2, WSM-3, WSM-4 and WSM-14, enable a more accurate measurement of the depth to groundwater beneath the facility, and confirm that releases are not occurring from the sludge lagoons.

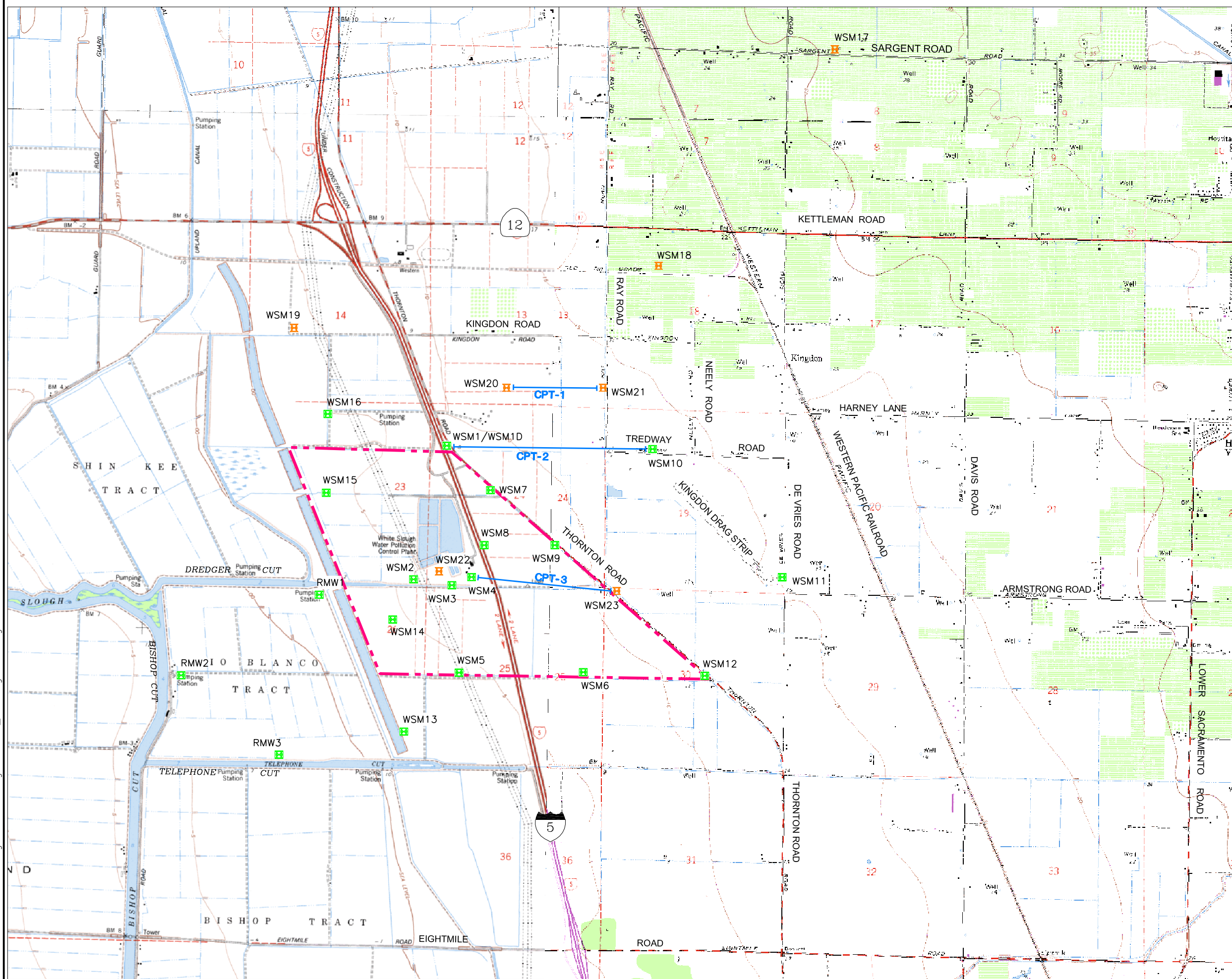
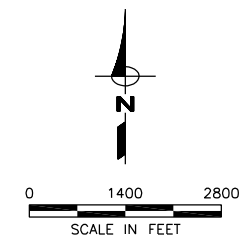


Figure 5-11
City of Lodi
White Slough WPCF
Groundwater Investigation
PROPOSED MONITORING WELL
AND CPT/HYDROPUNCH
LOCATIONS

LEGEND	
WSM12	EXISTING MONITORING WELL
WSM23	PROPOSED MONITORING WELL
CPT-1	PROPOSED CPT/HYDROPUNCH TRANSECT
	EXISTING CITY-OWNED LAND

- NOTES:**
1. CPT - Cone Penetrometer Test.
 2. WSM1D is a proposed deeper well located at the site of existing well WSM1. The depth of WSM1D will be determined based on the CPT/Hydropunch results from the west end of transect CPT-2.



Note that this list of wells encompasses all of the additional monitoring wells recommended in this report. In addition to these new wells, CPT/Hydropunch testing is recommended along the following three transects (Figure 5-11):

- From WSM-1 to WSM-10.
- From a new well located between the two confined animal facilities associated with the dairy that is adjacent to the City's property to a new well several thousand feet east (downgradient) of this dairy.
- From WSM-4 to a new well located on Thornton Road due east of WSM-4.

The CPT/Hydropunch transects should be performed and evaluated before drilling the wells on either end of the transects. Each CPT/Hydropunch location along the transects should be sampled at various depths. This depth versus nitrate concentration information should be evaluated to help determine the best completion depths for the monitoring wells on either end at the transects. Analyses of nitrogen and oxygen isotopes along the transects may help differentiate sources of nitrate, whether denitrification is occurring, and the extent of transport from these sources.

Additional information regarding the exact locations and construction details for the recommended monitoring wells and the CPT/Hydropunch testing will be provided in a forthcoming Groundwater Monitoring Workplan.